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APPLICATION OF LASER RANGING TECHNIQUE IN AIRBORNE FIRE-CONTROL

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Abstract: The airborne laser rangefinder can offer an accurate and economical solution for low altitude delivery of bombs. Recommendations for safety precautions and aircraft window are also made.

I. Function of Distance Information in Airborne Fire Control

1. Solution to problems of airborne fire control

Relying on their fire control systems, military aircraft release their weapons by pointing at the targets during strikes. In the fire control system, the computer solves for the theoretical point of the target position in the space coordinate system by using the mathematical model in software stored in internal memory. A display in the fire control system shows the theoretical point to the pilot, who is only required to maneuver the aircraft so that the theoretical point of the target position is moved to the actual point of the target with steady tracking for a short period of time, thus accomplishing the pointing. The

pilot is a sector in the large closed-circuit of the fire control system. The mathematical model of fire control relies on different fire control principles of pretracking, interception of firing, continuous calculation of the release point, or continuous calculation of the pointing line. Since an airborne fire control system has undergone its computer simulation, ground test simulation, and air test flight target striking, the fire control system can enable the released weapon to pass through the theoretical point after completion of pointing, thus striking the actual target. The above-mentioned process is the airborne fire control, in concise technical terms.

To complete the pointing mission, the airborne fire control system requires large amounts of initial information, such as aircraft velocity relative to the target, the distance of aircraft to target, dive angle of aircraft toward the target, and the attitude angle of the aircraft in order to measure aircraft movement, target position, and the deviation from the computed weapon trajectory relative to the released weapon.

2. Factors affecting precision of airborne fire control system

To ensure pointing accuracy, an airborne fire control system requires its measuring sensors to provide relatively high accuracy in initial information. For different kinds of weapons, and different firing methods, there can be some difference in the accuracy requirements of the initial information. Generally speaking, the error in velocity information should not exceed 1

to 2m/s; the measured error of angular information should not exceed several milliradians; and the measured error of distance information should not exceed several meters. Evidently, data matching in terms of accuracy among the various initial data should be maintained. If some data has a much greater error, the accuracy of the entire system is difficult to be enhanced. If the accuracy levels of other data cannot be high, it is senseless to buy an expensive sensor only for upgrading the accuracy of some information.

Airborne fire control systems typically employ gyroscopes and platforms as the inertial sensors to measure the movement of the aircraft proper, as well as the relative angular motion between aircraft and target, thus providing relatively high accuracy in velocity information and angular information to the fire control system. However, generally requirements on measurement accuracy cannot be satisfied in the distance information sensors generally used in airborne fire control systems.

In the view of some researchers, when applying low-accuracy distance information sensors, weapons can also be successively released and hit the target. We should emphasize that such success has a precondition of employing specific aircraft, well-known targets, and repeated training of pilots. Obviously, very high economic costs are required in carrying out these preconditions. Such high-priced experience has little reference values to the next combat missions and for other pilots.

Besides, with the advances in military technology, air defense capability of ground targets has been quite adequate; many ground targets have been skillfully camouflaged. Therefore, it is not easy for aircraft to discover targets with the opportunity of attacking the target at the first pass. In other words, there is a very low probability of destroying the target in the first pass.

Therefore, the development of highly precise distance information sensors to be applied in airborne fire control systems is very necessary.

II. Comparative Analysis of Several Airborne Distance-Measuring Approaches

Generally, an airborne fire control system employs distance-measuring arrangements, including three categories: visual measurement of distance from an external baseline, height, angle, and distance measurements, as well as direct distance measurement. There are the following pros and cons in comparative analysis.

1. Visual measurement of distance from an external baseline

The scheme of visual measurement of distance from an external baseline involves applying variable-diameter light rings provided in the fire control system to enclose the targets of specific sizes. From the field angle of the target related to a light ring, the distance to the target is calculated based on the trigonometric relationships between sides and angles.

The pros in the scheme of visual measurement of distance

from an external baseline is simplicity of equipment. The problem posed by this arrangement is as follows: the dimensions of large numbers of ground targets are difficult to be known in advance. On many occasions, one cannot proceed in distance measurement of ground targets. Although the dimensions of few air targets are known in advance, their projective dimensions on the plane of the light rings can only be roughly estimated, so accuracy in distance measurement is limited.

2. Measurement of height, angle, and distance

In the arrangements for height, angle, and distance measurements, first the height of the aircraft above the ground is measured by the height information sensor in the aircraft. Then, the sensor for the target angular information is used to measure the angle to the target, next the distance to the target is calculated based on trigonometric relationships between sides and angles.

There are two kinds of equipment used as aircraft height information sensors: barometric altimeter and radio altimeter. The barometric altimeter has limited sensitivity in its sensing units, thus the aircraft height information cannot be precisely measured. From the measured height above sea level one should subtract the height of the ground above sea level prior to computing the distance to the target. Although the radio altimeter can directly measure the vertical height of the aircraft, it cannot update the data in regard to the broken-terrain error. The measured height value may not be equal to the

aircraft height above the horizontal plane of the target.

When the aircraft enters the airspace at intermediate or high altitude, the effect on distance accuracy because of errors in height information may be allowable. However, when the aircraft enters the airspace at low altitudes or very low altitudes, the error in height information and the error in angular information all become the sensitive factors in accuracy as to distance information, thus seriously affecting accuracy in measuring the distance from the target.

3. Direct distance measurement by radio-frequency radar

The more ideal scheme is to apply direct measurements of distances with ground targets. The means of direct measurement of distance could include radio-frequency radar, or laser rangefinders. We first discuss radio-frequency radar.

For distance measurement with radio-frequency radar, it is not required to know in advance the target dimensions or the height and angle, thus avoiding errors associated with these sensors. Difficulties confronting the radio-frequency radar also occurs during low-altitude or very-low altitude flight. If the flight altitude of aircraft is 60m and the real-time distance from the target is 3.4km, then the pointing line of the aircraft to the target is only 1° with respect to the dip angle to the ground. Since the radio beam angle emitted by the radio-frequency radar should not be very narrow, it is impossible to have precise measurement of distance at such a small glancing angle. The fringe portion of the radio beam may also convey

false information due to reflection by other ground objects.

Of course, not all approaches are at the very-low altitudes category. However, the fire control system of military aircraft should provide more combat opportunities in order to ensure firing of weapons in the most strict conditions. If the fire control system cannot be used in very low-altitude flight, many combat missions are unable to be accomplished.

4. Direct distance measurement with lasers

Laser rangefinders are better than radio-frequency radar in the following aspects: even at very small glancing angles, the laser rangefinder can also accomplish the mission of precisely measuring the distance. One reason for this advantage is as follows: the laser beam has excellent orientational properties. The emitting angle of the laser beam after alignment by the optical system can be smaller than 1 milliradian. The second reason is as follows: a laser beam can operate in short pulses with very acute angles; its pulse duration can be shorter than 20ns.

From the approach of combat applications, a laser rangefinder has some other advantages. A laser rangefinder is still an optical device, not jammed by enemy electronic equipment, and also does not jam the electronic equipment in the aircraft. The emission of a laser beam can easily align with the pointing line and synchronously track the target. The laser rangefinder can be developed into a very small size and flexibility. Even an aircraft with a very crowded cockpit, space

can always be found for a laser rangefinder, thus not only to measure distance, but also to provide prewarning information to avoid certain terrain.

With regard to the foregoing, we can see the tactical significance and economic effectiveness of using a laser rangefinder in airborne fire control systems. Such airborne control systems can ensure success at the first pass and can reduce the number of sorties for accomplishing a combat mission, reducing the casualties due to ground artillery attacks, can acquire a target at the strike pass, can avoid expenditures of building simulation targets, can reduce the funds for flight training, and can shorten the time for training new pilots. At present, the air force has greater and greater interest in installing laser rangefinders in airborne fire control systems.

III. Requirements on Repetition Frequency of Laser Rangefinders

1. Intervals provided by distance information

Perhaps in the view of some people, only considering the weapon release approach, just one distance measurement over the target was enough. Once the information of target distance is provided, the fire control system can compute the residual distance value of the aircraft when flying at the weapon release point. If this value is fed into the execution mechanism to simultaneously display the release point sign in the monitor, the pilot can apply the release point sign to accomplish weapon release toward the target. Therefore, a laser rangefinder

requires only 1pps [pulse per second] or even a lower repetition frequency. Actually, this viewpoint is impractical because in a typical pass, the pilot does not have more than 5s for his strike opportunity. If the repetition frequency of the laser rangefinder is too low, the pilot may be unable to have timely distance measurement to the target. Or, the real-time distance cannot be measured because over-large interval values of distance information are provided by the laser rangefinder.

The laser rangefinder gives the distance information as soon as the laser beam is returned from the target, and detection is made by the receiver. Since the aircraft is in continuous flight, even if the target is fixed and motionless, the distance to the target is still continuously varying. The interval value between two distance data of the same target outputted by the laser rangefinder are determined by the repetition frequency of the laser rangefinder. The higher the repetition frequency, the smaller is the interval value; the lower the repetition frequency, the higher is the interval value. For an aircraft traveling at 800km/h, if the repetition frequency of the laser rangefinder is only 1pps, the interval value between two measurement data will be about 200m. However, the optimal release point of the weapon is perhaps at a certain point in this 200m. Therefore, whatever the adoption of the distance information prior to the optimal release point, or the distance information after the optimal release point, is not in real time, thus affecting the pointing accuracy and attack results.

2. Compromise between repetition frequency and cooling arrangement

The higher the repetition frequency of the laser rangefinder, the more heat is produced in distance measurements. In order to affect the service life and normal operation of the rangefinder, cooling can be employed to prevent a temperature rise. To install cooling devices on the laser rangefinder, power consumption is increased, as well as more volume and weight. Therefore, with respect to military aircraft, it is not welcome to install a laser rangefinder with cooling device. A compromise should be reached to design a high-repetition frequency in laser rangefinders and a simple cooling scheme.

The temperature rise in a laser rangefinder is related not only to repetition frequency, but also related to the medium and material used in making the laser device. For example, the heat consumption of neodymium glass is relatively high, not adaptable to laser rangefinders with a high repetition frequency. However, the temperature rise in neodymium yttrium and aluminum garnet is limited. If the laser cavity is designed properly, the laser device so fabricated can operate continuously with a high repetition frequency of 10pps without having a special external cooling apparatus installed, thus becoming more suitable for airborne fire control systems.

IV. Laser Caused Injury and Eye Protection

For laser beams with higher energy density, when the beam passes through the pupil and is focused onto the retina by the

eyeball, the laser beam energy will have a heating effect on the upper epidermis and the vascular membrane of the pigment in the retina, causing burn injuries to the retina, or retinal bleeding. For higher energy-density laser beams, chain-reaction injuries and profuse retinal hemorrhaging may result.

After the retina is injured, first white floaters hindering sight may appear in the patient's visual view. About two weeks later, the white floaters become black floaters. When the patient observes white objects, the black floaters always reappear, moving with shifting of the line of sight. Actually, such black floaters are blind floaters. Not only can a high-energy laser beam lead to eye injuries, even a low-energy beam can also lead to undesirable results. Although the initial injury due to low-energy lasers can be recovered from, however, multiple repeated injuries can also lead to permanent blind spots.

From the foregoing, protective measures should be taken for persons engaging in research of laser applications and in operating laser devices, in order not to lead to eye injuries by direct laser beams from a laser device, or from an indirect laser beam reflected from a reflective mirror. The protective measures are simple and effective, such as installing safety barrier plate, or wearing laser protective eyeglasses.

V. Counter Requirements on Aircraft Windows by Laser Rangefinders

A series of requirements are raised by military aircraft

with laser rangefinders. To sufficiently exploit the performance of laser rangefinders, and to raise the overall quality of fire control systems, there are some counter-requirements on aircraft window design due to laser rangefinders. These counter-requirements can be presented as follows:

1. Window material and machining

Window material should have higher transmissivity for all wavelengths of laser devices. The windows should be ground and polished to attain the optical quality standard as specified. For example, in the range that laser beams can reach at the window plane, distortions greater than one-quarter wavelength should not be present; this is equivalent to one diaphragm. The wedge angle between two window surfaces should not be greater than 1mrad. In addition, antireflective coatings should be applied to the internal surfaces of windows. Such coatings allow the highest transmissivity at the average incident angle of a laser beam.

2. Window strength and installation

Whether in combat applications or in parking at an airport, aircraft windows should withstand static pressure and dynamic pressure, be capable of resisting bird strikes, rain scouring, and hail hits. The windows should be installed with an inclination relative to the laser beam. In the entire transmission aperture of the light beam, any light in the beam should not have an angle less than 10deg in order to prevent the response of a receiving component when the emitted laser beam is

returned through the window.

3. Measures of preventing frost and fog

In flight or parking conditions, aircraft windows may have frost or fog condensations. Means of removing this frost and condensation should be considered. In the present measures, the best scheme is to pass hot dry gases between the window and the rangefinder.

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Brief author's resume: Li Chunliang, male, was born in December 1941. He is a senior engineer, presently engaged in optical system design of flat displays and other airborne optical systems of airborne electro-optical equipment.

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